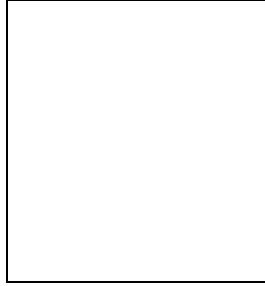# Results from the short baseline experiments at CERN

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Considerations based on particle physics (in particular the so-called see-saw mechanism) and on cosmology, in relation to the Dark Matter question, motivated the search for $\nu_\mu \to \nu_\tau$ oscillation in the region of small mixing angles. We present here the outcome of the short-baseline programme carried out at CERN by the CHORUS and NOMAD experiments. Both experiments are about to publish their final results. At values of $\Delta m_{\mu\tau}^2$ greater than 1 eV^2 oscillations between ν_μ and ν_τ are excluded at 90% C.L. down to $\sin^2 2\theta_{\mu\tau} \sim O(10^{-4})$.

1 Introduction

The discovery of neutrino oscillations represents today the most powerful and elegant way to establish the non zero mass of the neutrino and a non vanishing mixing matrix between weak eigenstates in the leptonic sector [1].

Among neutrino oscillation searches the $\nu_\mu \to \nu_\tau$ channel is a highly promising one to pursue with accelerators; given the high mass of the τ lepton it is in fact relatively easy to produce a neutrino beam in which ν_τ are practically absent. The detection of ν_τ charged-current interactions in such a beam will prove with no doubt the mixing among different neutrino flavors.

Indications on the possible presence of mixing in the $\mu - \tau$ sector at small mixing angles and at cosmological relevant squared mass difference in relation to the question of Dark Matter [2], led to the construction of CHORUS and NOMAD, two short-baseline experiments using different techniques to detect ν_τ appearance. So far, there is no evidence from these experiments of such a phenomenon even though the data analysis is not yet completed.

2 Short-baseline programme at CERN

Two short-baseline experiments have recently taken data at CERN and are about to finalize their data analysis. Both of them aim at the detection of $\nu_\mu \to \nu_\tau$ oscillation via the ν_τ
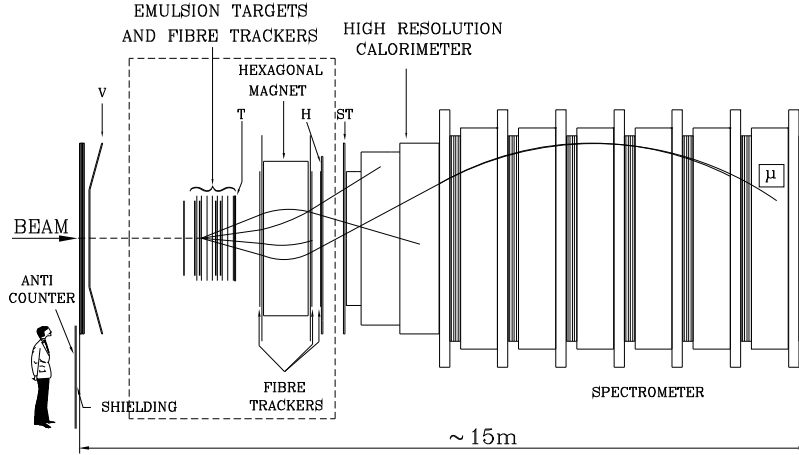
Figure 1: General layout of the CHORUS detector.

appearance method, using the CERN SPS Wide Band Neutrino Beam [3]. The beam contains predominantly muon neutrinos from π^+ and K^+ decay, with contamination levels for $\overline{\nu}_\mu$ and $\nu_e, \overline{\nu}_e$ of, respectively, 5% and 1%. Neutrinos are mostly produced in a 290 m long decay tunnel, at an average distance of about 625 m from the experimental hall. The estimated ν_τ background is of the order of 3.3×10^{-6} ν_τ charged-current interactions per ν_μ charged-current interaction[4] and is therefore negligible. The ν_μ component of the beam has an average energy of 27 GeV.

2.1 The CHORUS experiment

The CHORUS apparatus[5] is shown in Figure 1; it comprises an emulsion target, a scintillating-fiber tracker system, trigger hodoscopes, a magnetic spectrometer, a lead scintillating-fiber calorimeter and a magnetized iron muon spectrometer.

The emulsion target has the unprecedented mass of 770 kg and a surface area of 1.42×1.44 m^2. Neutrino interactions occur in nuclear emulsion, whose exceptional spatial resolution (below 1 μm) and hit density (300 grains/mm along the track) allow a complete three-dimensional reconstruction of the event. The direct evidence of τ production and decay is thus obtained analyzing the trajectories of the charged particles near the interaction vertex. A "kink" characterizes interesting events.

Electronic detectors downstream the emulsion target are used to locate the event and, to a lesser extent, to reconstruct the event kinematics.

The detector has been exposed to the neutrino beam from 1994 to 1997, for a total of 5.06×10^{19} protons on target. A total of about 1×10^6 events have been reconstructed in the electronic detectors to have the interaction vertex in the emulsion.

The number of neutrino interactions located in the emulsion target until now is 144K and 23K, respectively for CC-like and NC-like events. As described in details in the last published paper[6], no τ^- decay candidates have been found so far. The expected number of background events are 0.1 and 1.1 for the τ decay channels to μ^- and h^-, respectively. The overall 90% C.L. upper limit on the number of τ decays is 2.4 and has been determined using the method proposed by Junk[7] which allows the combination of different channels, taking into account the errors on the background and on the signal. This implies that oscillation parameters lie outside the 90% C.L. curve shown in Figure 3, corresponding to an oscillation probability $P_{\mu\tau} < 3.4 \times 10^{-4}$ and to $\sin^2 2\theta_{\mu\tau} < 6.8 \times 10^{-4}$ for large $\Delta \mathrm{m}^2_{\mu\tau}$.

The CHORUS experiment is still analyzing neutrino interactions occurred into the emulsion target; at the end of the analysis it will reach a sensitivity corresponding, in case of negative result and no background, to a limit on the $\nu_\mu \rightarrow \nu_\tau$ oscillation probability of $P_{\mu\tau} < 1.0 \times 10^{-4}$.
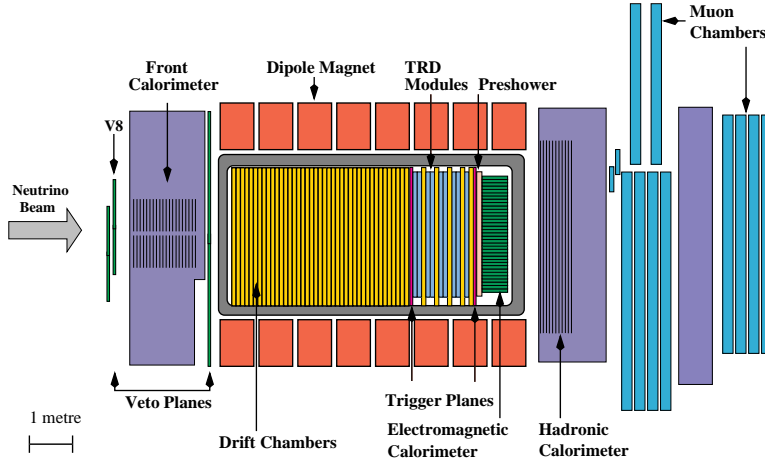
Figure 2: Side view of the NOMAD detector.

Due to the electron-neutrino contamination in the beam, the absence of tau candidates events can be used to quote also a limit on the $\nu_e \to \nu_\tau$ oscillation probability. Using the above sample of analyzed events a limit of $P_{e\tau} < 2.6 \times 10^{-2}$ at 90% C.L. has been obtained. Full $\nu_e \to \nu_\tau$ mixing is excluded at 90% C.L. for $\Delta m^2_{e\tau} > 7.5$ eV^2; large $\Delta m^2_{e\tau}$ values are excluded at 90% C.L. for $\sin^2 2\theta_{e\tau} > 5.2 \times 10^{-2}$.

2.2   The NOMAD experiment

The NOMAD detector is described in detail in reference [8] and shown in Figure 2. It consists of an active target made of drift chambers placed inside the former UA1 dipole magnet, with a field of 0.4 Tesla perpendicular to the neutrino beam direction. The total mass of the target is about 2.7 T. The target is followed by a transition radiation detector (TRD) and by a lead glass e.m. calorimeter, together giving a good electron/hadron separation.

The experiment took data from 1995 to 1998 collecting a sample of about 950K ν_μ neutrino charged-current interactions.

The NOMAD experiment searches for ν_τ charged-current interactions by identifying τ^- decays to $e^- \bar{\nu}_e \nu_\tau$, inclusive decays to one or three charged hadron(s) $+ \nu_\tau$ and exclusive decays to $\rho^- \nu_\tau$, for a total branching ratio fraction of about 82%. Since the identification of these reactions is achieved using only kinematic criteria, a good particle identification and a precise momentum measurement of all secondaries is required.

The criteria to select τ^- decays among charged and neutral current ν_μ interaction relies on the presence of isolated τ decay products in the final state and on the correlation in the transverse plane among their momentum, the total hadronic system momentum and the missing momentum. A special search for τ^- decays is also performed in a specific sample of events characterized by low primary track multiplicity (less than 4), enriched by quasi-elastic and resonance production.

The combined analysis of all different τ decay modes shows no evidence for $\nu_\mu \to \nu_\tau$ oscillation [9]. To obtain its final result the NOMAD collaboration has adopted the technique proposed by Feldman and Cousins [10]. The resulting 90% C.L. upper limit on the oscillation probability is shown in Figure 3; at present $P_{\mu\tau} < 1.7 \times 10^{-4}$, which corresponds to $\sin^2 2\theta_{\mu\tau} < 3.4 \times 10^{-4}$ for large $\Delta m^2_{\mu\tau}$. The sensitivity of the experiment is 2.5×10^{-4}; this is higher than the quoted confidence limit, since the number of observed events is smaller than the estimated background. In the absence of signal events, the probability to obtain an upper limit of 1.7×10^{-4} or lower is 39%.

A similar analysis has been performed in order to check the $\nu_e \to \nu_\tau$ hypothesis; the 90% C.L.
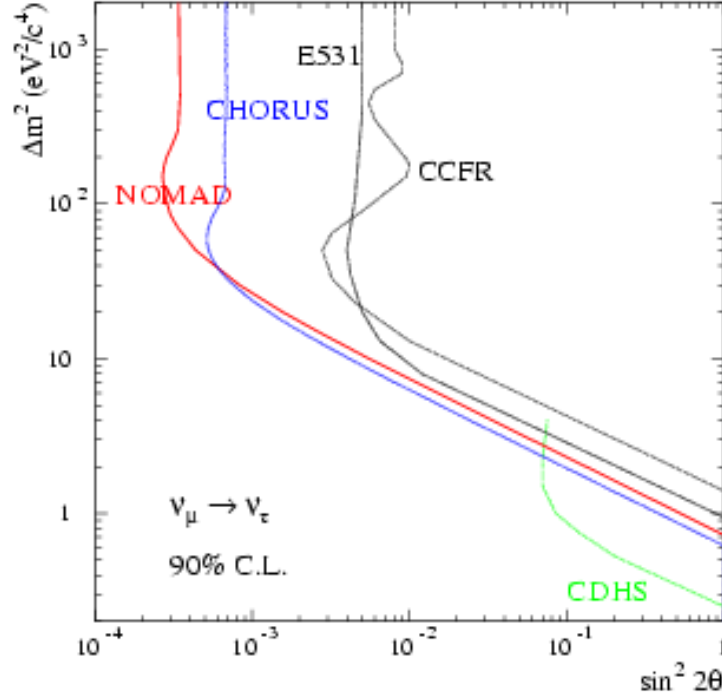
Figure 3: Chorus and NOMAD exclusion curves in the $\nu_\mu \to \nu_\tau$ two flavor parameter space.

upper limit on the oscillation probability is $P_{e\tau} < 0.8 \times 10^{-2}$, which corresponds to $\sin^2 2\theta_{e\tau} < 1.6 \times 10^{-2}$ for large $\Delta m^2_{e\tau}$. The experiment sensitivity is 1.2×10^{-2}. In the absence of signal events, the probability to obtain an upper limit of 0.8×10^{-2} or lower is 43%.

3 Conclusions

The outcome of the CERN short baseline $\nu_\mu \to \nu_\tau$ oscillation programme was presented. Particle physics motivations based on the see-saw mechanism and on cosmological arguments were at the basis of CHORUS and NOMAD experiments, carried out at CERN to search mainly for small mixing angles and relatively high mass differences in the $\mu - \tau$ sector. The results obtained so far by these two experiments do not show evidence of neutrino flavor oscillation.

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